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Decision-support tools for municipal infrastructure maintenance management

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Abstract

Sewers, water pipes, and streets are elements of our civil infrastructure, the supporting structure of society. Infrastructure is a complex technical system that provides us with a varied range of essential services; a storehouse of resources and wealth that each generation inherits, uses, and passes on to succeeding generations.
The asset management has a big influence on infrastructure development and use: undertaken and executed without fully recognizing the complexity, diversity, and social and technological evolution of the system almost inevitably squander economic, environmental, social, and cultural resources.
The challenges of managing these assets most effectively are substantial: the inefficiencies are widespread and really easy to see: jammed traffic on roads designed to carry only a fraction of the current demand, newly-resurfaced city streets open to repair aged subsurface pipes, basements flooded in case of insistent heavy rain, etc.
In existing asset management systems often information is not efficiently used in decisional process, which results in much waste in time and effort. It is necessary to develop life-cycle management systems of infrastructure to overcome this problem. The system must integrate geographic information, design data, inspection and maintenance data. Emphasis is placed on development of decision-support tools for municipal infrastructure management. The study identifies the challenges for maintenance, repair and renewal planning faced by asset owners and managers. Integration with existing systems such as Computerized Maintenance Management Systems, Geographic Information Systems, is seen as the largest challenge for developing and using decision-support tools in the area of asset management.

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Keywors: Infrastructures, asset management, maintenance, decision-support tools, Computerized Maintenance Management Systems, Geographic Information Systems, integration, interoperability.

1. Introduction

Urban realities are characterized by several phenomena, such as the economic globalization and the increasing international competition among cities; complexity has become a paradigm of postmodern architecture condition, and not only, dictating the need to investigate the limits and the practicability itself of any project dimension, and making thus inadequate the existing theories and tools to face long term challenges.

In such a scenery, the problem of determining the modalities of optimizing the urban infrastructure asset management and maintenance becomes urgent as a result of several causes: the progressive decrease in financial availabilities of Public Administrations despite the substantial assets, the higher citizens/users' attention to the

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supplied service quantity/quality, the interest in public health and safety requiring a renovated focus on the themes of water and air quality, the green spaces, the reduction in vehicle traffic and noise, the population ageing and the consequent difficulties in accessing town services, the obsolescence of many infrastructures realized during the town growths, the increase in social and economic costs of management and maintenance services (even in terms of environmental resources).

Planning and managing the urban asset maintenance show particular complexity, since the system to be regulated and controlled is characterized by a multiplicity of subsystems - with their mutual relationships and multiple functions – and subjects involved in planning and carrying out the maintaining actions, as well as by a multiplicity of user typologies.

It is then necessary to operate conceiving towns as integrated systems useful to produce services indispensable for carrying out urban functions, in order to easily foresee over time a careful intervention planning which takes account of the asset life cycle and of the infrastructure relationship systems as well: an integrated approach which, by overcoming the separation between emergency management and urban environment technical management, finally starts operated in a systemic way, considering the town as a unitary body [1].

With regard to the above mentioned issues, the Italian studies developed in the technological area have given important contributions especially in defining the specificity of the process objects in maintenance on an urban scale; it seems therefore necessary to arrange operational tools aiming at improving the effectiveness of decisional process in managing and maintaining urban infrastructures, in order to enhance the capacity of choice prediction – in the short and long term – as well to as to develop an integrated approach to evaluate technical, economic and financial factors useful to pursue objectives related to existing services in relation to the whole urban body.

2. Towards an integrated infrastructure management

Urban services are subjected to a multiplicity of sinergically interacting sub-systems: the public building asset fulfilling several functions, comprising the water adduction and disposal systems, the energy adduction and information, the circulation, to which it is necessary to add, differently interpreted in terms of density and quality, and more and more important, the green system. Moreover, we should add other elements strongly characterizing the urban environment such as road signs, urban furniture and the connective network which determines spaces differently interpreted in terms of hierarchies and functions.

Molinari makes a systematic list of urban subsystems, grouped into three macro-categories related to a possible integrated management. The first group includes a *network structures* (electrical energy distribution, traffic lights and lighting system, gas distribution, telephone and telematic networks, water systems - stormwater, greywater and blackwater - road network, etc) generally managed by fragmented public bodies. The second group includes the *widespread structures* (road signs and urban design), consisting in all those elements widespread over the town territory having a relevant impact on the town image and its functioning.

The third group includes the *punctual structures* (hospitals, schools, monuments, public equipment, sport centers, etc) whose malfunctioning doesn't generate negative effects on other subsystems.

It should be pointed out the problem of using the road sections as an undifferentiated container of an elevated number of near infrastructures, each one having a corresponding regulatory authority, with high influences on others in case of failure or maintenance [2].

A crucial goal - within which it becomes necessary to compare the development of tools improving the decisional process when planning the urban system management and maintenance, especially in the network systems management – is then to acquire an integrated approach: by pursuing such objective, when planning new buildings or maintaining old or degraded parts of road networks and subservices, it will be possible to get advantages such maintaining a high service level and minimizing the life cycle costs, the impact on environment, the disruptions to traffic and residents. Pursuing integration in construction and maintenance of linear infrastructure is a difficult but indispensable task (networks are managed by authorities or societies characterized by different operational modes) in order to overcome the irrationality of current operating modes, characterized by a substantial disinterest in the effects of mutual interference among systems (losses and breaks on water mains can result in breaks or degradation on the nearby wastewater mains or street network; at the same time, the sewage deterioration can undermine the nearby water and street structure; the vibrations generated during street rehabilitation/reconstruction can cause the underground structures collapse; the fluxes of electric energy from electric lines, railways or cathodic protection systems can accelerate the electrolytic corrosion of metal pipes) and by a great waste of economic and environmental resources; such an important objective can represent a specific contribution on an urban scale from maintenance programming and management, aiming to raise performance and lifetime levels of network systems, and to achieve a sustainable city.

Fig. 1. It is necessary to overcome the irrationality of current operating modes, characterized by a substantial disinterest in the effects of mutual interference among systems.

The nowadays challenge characterizing the contemporary city government is then to research, define and experiment specific tools to manage interventions on the existing asset, aiming at the quality of the overall town and its functions.

Methodologies and tools should indeed be directed to support Public Administrations, to identify needs, to assess solutions and to plan actions over the medium and long term in order to obtain better performances in urban systems, by optimizing the financial and environmental costs; in a word, optimization methods are required in the decisional processes in order to constantly improve resources in terms of performances and supplied service levels.

3. DSS to manage and maintain urban infrastructures

Managers in Public Administrations and agencies daily have to take relevant technical and financial decisions on "*what, how and when*" to maintain, repair or renew in urban assets, in order to maintain acceptable levels of infrastructure performance, taking into account that, within a local community, the infrastructure efficiency is strictly linked to social and economic implications.

Within the asset management it is necessary to determine, for each part, which maintenance policy is possible to activate, how to assess it residual life, which are the failure probabilities and the possible consequences of a break, what are the best requalification/maintenance techniques - and their related costs - for a significant increase in the residual life time. In order to achieve this, it is crucial to plan and activate several activities through which to define the qualitative and quantitative characteristics of assets, to know the degradation state and the supplied performance levels, to determine the degradation and intervention sceneries, to define alternative technical and economical policies, to assess risks, to determine priority maintenance actions, to control the effectiveness of implemented interventions.

An asset manager won't have an easy task since, in most cases, it is necessary to allocate poor resources against a multiplicity of exigencies within a decisional context often characterized by a substantial lack of data or based on approximate models. The decisional process, moreover, is being more and more carried out in variability and uncertainty conditions, caused by important changes within the management policies such as budget and staff reductions, privatizations or outsourcings - which make highly difficult the action prediction over a time horizon compatible with the asset life cycle.

It becomes then evident the exigency of developing process technologies aiming at optimizing the efficiency and effectiveness of infrastructure management within more and more complex contexts, as well as the necessity of re-thinking the optimization modalities of decisional processes by implementing tools supporting the activation of technical and financial management policies.

Given the qualitative and quantitative importance of the information crucial to determine an effective decisional process, of undoubted relevance becomes the development of information solutions capable of integrating the several aspects of infrastructure management as well as of allowing the information sharing.

Since the 90's, new technologies and methods were developed in order to improve the management process. In effect, many software systems were implemented to improve the management capacity of public administrations and agencies; significant progresses have been made thanks to the development of tools within the management of road and bridge pavement as well as of water and wastewater systems. Such progresses are characterized by a multiplicity of important functions such as the feedback data management, the planning maintenance management, the works management, the probabilistic models of degradation, the life cycle cost analysis, the performance levels of supplied services. At the same time, they were all conceived for single systems, far from an infrastructure integrated vision and from the capacity of interoperability with others tools.

Venier, researcher at the National Research Council, Canada, has defined an exhaustive tool frame useful to support the technical and economical decisions related to the infrastructure asset maintenance [3]: Computerized Maintenance Management System (CMMS) is the most famous and widespread. At the moment, it is possible to buy a wide range of this kind of software, and they are generally relational database applications developed on the base of the asset managers' needs, and some of these can manage work orders, emergency calls, storage inventory, equipment lists, programmed maintenance plans, expenditure level control, invoice emission. A lot of work still has still has to be done to improve database on failure modes and related intervention techniques, as well as to develop possible risk analysis: it is not yet a tool through which it is possible to develop long time infrastructure management.

In order to evaluate systems conditions, the Condition Assessment Survey System (CASS) is an important tools: it is a DSS which based on benchmarks to compare several infrastructures of the same type or only one infrastructure in different service times.

The CASS assesses the inefficiencies of a system or component, the defect identity, the urgency of repairing works, and in some cases it calls for estimated repair costs when controlling.

The US Army Construction Engineering Research Laboratory has elaborated the Engineered Systems Management (EMS), a system to manage different kinds of components and infrastructures such as road pavements, roofs and railway systems. It is based on the attribution of a condition index (CI) to an infrastructure, on the base of several factors: building quality, material quality, degradation conditions, degradation extent. The software can assess the possible IC evolution curve depending on the intensity of infrastructure use and the possible external degradation actions.

It emerges that the management tools for infrastructure assets nowadays used can substantially govern only specific aspects in the management process or one single type of infrastructure: the EMS deals only with the road pavement condition evaluation, the CASS and CMMS exclusively manage the work operative assessment. Consequently, they still have to be considered as partial approaches to solve the complex instance represented by the need of acquiring inputs from a variety of users (technical, administrative and financial staff), of communicate in an effective way within a wide set of applications as well as of furnishing useful data on a decisional and operative level (from the management to the technical staff to the coordination of work teams).

Most softwares were developed in order to work as stand-alone systems with limited or inexistent possibilities to share and exchange information: each software generally uses specific data models. The information exchange among such softwares needs then to be done by means of manual data entry, which is through a process substantially inefficient, expensive and subjected to interpretation mistakes.

Within the asset management, the decisional support tools available at the moment allow only one approach to some aspects of infrastructure management; anyway, new and interesting developments can be found in geographical systems.

4. Spatial Decision Support System

The primary goal of an infrastructure management system is to reach and manage defined, updated and reliable data on the physical and performance characteristics of infrastructure assets, in order to allow the user a simple, quick and efficient access to data, by means of which to detect and predict the performance levels given by infrastructures, to plan the maintenance works and to allocate financial resources.

Such goal asks for carrying out several activities such as collecting and managing – in a quick and accurate way - data on infrastructure conditions and performances, adopting simulation models of infrastructure degradation modes as well as models for investment planning.

The crucial issue is to maintain precision, consistency and integrity in the infrastructure data, and to keep them updated in order to reflect the current degradation state of infrastructures and their performances.

The development and spread of CMMS has in effect highly improved the efficiency and economy of infrastructure asset management; anyway, thanks to the increasing number of softwares covering different aspects of infrastructure management, the great challenge of such process is to implement the existing tools within an integrated environment capable of carrying out both their uninterrupted integration and their data sharing.

The willingness to integrate space data with inventory data, to improve access as well as the management capacity, in the last decade have involved the development of SDSS (Spatial Decision Support System): an interactive system, computer based, projected to support a user of a group of users in reaching a better efficiency in the decision process. An SDSS is a tool supporting decisions in GIS environment; it generally uses a variety of spatial and non spatial information; the GIS technology represents, in effect, a powerful tool to activate more intuitive and efficient data queries, explorations and visualizations in their spatial context.

By means of a GIS it is possible to pursue a more holistic approach in which organizational and technical aspects can be involved within the different decisional levels: at a micro level, the technical approach prevails, while at a macro level useful information emerge to help political and thus strategic decisions. Such levels are, obviously, interdependent and complementary.

The spatial information management is based on the idea that data, users, softwares and hardwares interact in order to obtain a simpler vision of complex problems, to make decisions on the base of a higher understanding of reality.

The Geographical information Systems (GIS) are more and more widespread within public administrations, in order to face the exigencies of territorial government. In a GIS, the data related to a specific infrastructure are in direct relation with their geographical position in the town or territory map; for example, a given area can be visualized within the near lots, so that the surface or distance between objects can be calculated.

A Geographic Information System or GIS helps store, manage, analyze, manipulate and display data (i.e. tree location) that are linked spatially. In essence, GIS relates database records and their associated attribute data (i.e. tree essence, diameter and age) to a physical location, thereby creating a “smart map”. Visualization of discrete parts of these data on a GIS map is possible by layering the data into different “themes” (e.g. utilities, roads, buildings, parks, rivers). GIS applications can then display the intersection of various “themes”, as well as the spatial relationships between various features (i.e. pipe condition and soil type).

Recent progresses in geo-spatial technologies, together with a progressive decrease in their costs, have led many local realities to try to develop tools aiming at improving the process of managing, maintaining and planning process urban infrastructures; anyway, in spite of some encouraging progress, a spatial decisional support governing all aspects of infrastructure management hasn’t been fully developed yet [4].

In particular, the necessity to share territory information among all subjects involved in the technology networks management, represents one of the most crucial requirements to guarantee a coordinated management, even though the problem of information system integration and interface is still one of the most difficult to overcome.

Within the international context, it emerges the development of experiences aiming at overcoming such condition by means of a change in the geographic information sciences based on the development of open and distributed systems: the so called Spatial Data Infrastructure (SDI), consisting of a set of technologies, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain and preserve geospatial data.

An SDI has the fundamental goal to save resources by sharing of geographical information, by integrating the wide quantity of existing geospatial data into a unique “virtual database” on whose base to develop services to offer on the internet (webservices).

The development of an IDT is essentially based on using new information technologies, since they allow data and services involved to be interoperable.

The use of territorial and environmental information – managed by public bodies – represents the necessary condition to control and manage a territory and the interoperability among the different information systems, and it becomes crucial for an information exchange through which coordinate municipalities, authorities and businesses.

The condition for the development of support tools to territory decisions is thus the definition of interoperability rules, standards and models by means of which Pubic Administrations can go on with their information projects and spread and extend the information use.

5. Conclusions

In all local communities, the main functions to govern territorial infrastructure aren't "*planning and building*" anymore, but "*repair, re-qualify and replace*". The technical and administrative officers can make more efficient choices to govern the assets if decisions are based on deep engineering and maintenance knowledge as well as on the availability of reliable and updated data.

It is a matter of fact that information technologies represent a crucial part in any supporting decisional tool within asset management; an efficient data management becomes indeed a key element for the improvement of the decisional process related to municipal infrastructure management.

There are interesting support applications to the decisional process within the asset management, but still there isn't a solution which can solve the multiplicity of needs of investment management and planning in infrastructure renewal activities. The integration among systems requires to be the first challenge to improve the efficacy.

An unavoidable goal for future developments is undoubtedly the data integration. It is important that Public Administrations and Authorities - which are developing this kind of tools – share their own experiences and best practices.

The use of territorial and environmental information managed by public bodies represents the necessary condition to control and manage territories, but at the same time it will be crucial the definition of rules, standards, models for logic interoperability and clear access regulations.

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N.A.

Michele Di Sivo is the author of "*Introduction*" and , "*Towards an integrated infrastructure management*"; Daniela Ladiana is the author of "*DSS to manage and maintain urban infrastructures*", "*Spatial Decision Support System*" and "*Conclusions*".